Transactions of the Royal Society of S. Aust. (1993), **117**(2), 67-76.

BIOLOGY OF *ETIELLA BEHRII* ZELLER (LEPIDOPTERA: PYRALIDAE): A PEST OF SEED LUCERNE IN SOUTH AUSTRALIA

by A. D. AUSTIN, T. C. R. WHITE, D. A. MAELZER & D. G. TAYLOR*

Summary

AUSTIN, A. D., WHITE, T. C. R., MAELZER, D. A. & TAYLOR, D. G. (1993) Biology of *Etiella behrii* Zeller (Lepidoptera: Pyralidae): a pest of seed lucerne in South Australia. *Trans. R. Soc. S. Aust.* 117(2), 67-76, 4 June, 1993.

The general biology of the pyralid moth, *Etiella behrii* Zeller, a serious but sporadic pest of lucerne seed crops in South Australia, is documented. Larvae are recorded as feeding on six native and 18 introduced legume species. Head capsule widths of field-collected larvae show that *E. behrii*, like other pyralids, has five instars. Light-trap catches indicate the presence of at least four overlapping generations per year in the Adelaide area, with the majority of moths occurring during three generations from August to February. In lucerne crops in the Keith area, 150 km south-east of Adelaide, young and mature green pods suitable for oviposition are available from October to February. Two peaks in moth catches were recorded in late December and late January, respectively. Until mid-January, the number of eggs was strongly correlated with the numbers of moths caught, but thereafter the numbers of eggs and larvae decreased, with the second peak of moths giving rise to very few larvae. These observations are in agreement with the opinion of farmers that early lucerne crops are more heavily infested with *E. behrii* than late crops. Surveys of vegetation in the Keith area show that native host plants are very scarce, and that volunteer lucerne plants along road-sides and irrigation banks are the likely source of early infestations in lucerne crops. Mortality agents recorded include ten species of parasitoids, two pathogens and a number of general heteropteran and spider predators. These and other possibilities are discussed as factors leading to the observed decrease in larval numbers in mid to late January, a time when lucerne crops still contain a large proportion of green pods suitable for larval development.

KEY WORDS. *Etiella behrii*, Pyralidae, ecology, life history, lucerne, alfalfa, host plants, parasitoids, predators, pathogens.

Introduction

One of the most serious pests which can limit the production of lucerne seed in South Australia is *Etiella behrii* Zeller (lucerne seed web moth) (Maelzer *et al.* 1982a, 1982b; Durham 1984; Austin *et al.* 1986). It is one of seven species of *Etiella*, the larvae of which feed on the seeds of legumes (Whalley 1973). The most widespread and economically important species is the cosmopolitan *E. zinckenella* (Treitschke), a serious pest of legumes in many parts of the world, which in Australia is known only from Queensland (Abdul-Nasr & Awadalla 1957; Stone 1965; Singh & Dhooria 1971; Whalley 1973; Common 1990). The remaining six species are restricted to Australia, parts of south-east Asia and some Pacific islands. Only three species, *E. chrysoporella* Meyrick, *E. hobsoni* (Butler) and *E. behrii*, are recorded from South Australia; the former two only rarely as adults, and only from the northern and western parts of the State. The multivoltine *E. behrii* is a widespread and common pest throughout Australia, and of economic significance because of its heavy but sporadic outbreaks in dryland and irrigated crops of seed lucerne.

* Department of Crop Protection, Waite Agricultural Research Institute, University of Adelaide, Glen Osmond, S. Aust. 5064.

Little is known of the general biology or ecology of *E. behrii*, possibly because of its sporadic occurrence. In most years it does little damage to lucerne seed crops in S.A., but occasionally it causes widespread damage. At such times the species is also reported to damage lupins, field peas and some clovers, e.g. in 1954 and 1971 (Austin *et al.* 1986; DAM and DGT, unpubl.). *E. behrii* is thought to live on native plants along road-sides and in patches of scrubland during spring and early summer before infesting lucerne seed crops in mid summer, but this has not been confirmed. The present study was therefore undertaken to elucidate this part of its phenology and to document its general biology. Data have been included from a pest management program on lucerne seed crops (see Maelzer *et al.* 1982a, 1982b; Durham 1984), information collected in 1959-60 (by DGT), and life history studies undertaken during 1980-82.

Materials and Methods

Location of study

The project was centred on a property ('Brecon') 10 km south of Keith, S.A., in the middle of a major area of lucerne seed production. The area has a Mediterranean-type climate with mostly cold, wet winters and hot, dry summers (Anon. 1987). The

average rainfall for the area is 471 mm per annum. The early (spring) dryland lucerne crops are watered naturally by rainfall, but the majority of the seed crops are managed to flower in mid-summer and are irrigated, mostly by flood irrigation rather than by sprinklers. Work in the Adelaide area, which has a similar climate to Keith, was carried out in 1959-60 and was centred at the Waite Institute campus of the University of Adelaide.

Trap catches of adult moths

Adults were caught at a light trap each night in two separate studies in widely different years: over the period 1.iii.1959 to 18.ii.1960 on the Waite Institute campus (by DGT) and from 1.xii.1981 to 20.ii.1982 at 'Brecon' (by DAM). The second period of trapping was part of a general program of sampling insects in lucerne seed crops (Maelzer *et al.* 1982a, 1982b). The light trap in 1959-60 was a mercury-vapour type, while that used in 1981-82 was a 15 watt blacklight type (cf. Hardstaek *et al.* 1979), located in the middle of a lucerne area containing both dryland (early) and irrigated (late) crops.

Sampling eggs and larvae from lucerne crops

Five sampling sites were selected at 'Brecon' around a field of lucerne which was to be irrigated later that summer. All were dryland areas (i.e. not irrigated) and were of the commonly grown Australian cultivar, Hunter River. Each had been closed off to grazing animals some weeks earlier and contained lucerne plants with flowers and pods. Samples were collected from these sites about once per week from the beginning of December 1981 until mid January 1982 and taken back to the laboratory. Ten small samples (each of about 50 pods) were also taken from one or two more distant, dryland sites (up to 30 km away), including fields of lupins with volunteer lucerne plants.

Each sample was taken by walking through an area of 4-5 ha and picking stems of lucerne with flowers and pods from a number of widely spread points until 15-20 stems had been gathered. The stems were temporarily stored in a plastic bag on ice. In the laboratory each stem was searched, from the oldest raceme upwards, and each pod on each raceme was examined for eggs and larvae on the outside, and larvae inside. The procedure was continued until approximately 200 pods had been inspected. This meant searching from 1-12 stems ($\bar{x}$ = 5.0; S.D. = 1.9) bearing from 1-11 racemes each ($\bar{x}$ = 5.3; S.D. = 2.3). The racemes on any one stem were at any stage from unopened flowers to fully matured brown (dry) pods. All stages of flowers and pods were usually present on a single stem and, wherever possible, stems were selected that had some well-developed pods. For each raceme a record was made of the number of *E. behrii* eggs and larvae (classed as instars: 1 + 2, 3 + 4, or 5) and the stage of development of the pods (classed as flowers, pods just forming, juvenile pods, young pods, mature green pods and mature brown pods – see Fig. 1). In earlier samples, no stages of *E. behrii* had been found on flowers, on pods that were just

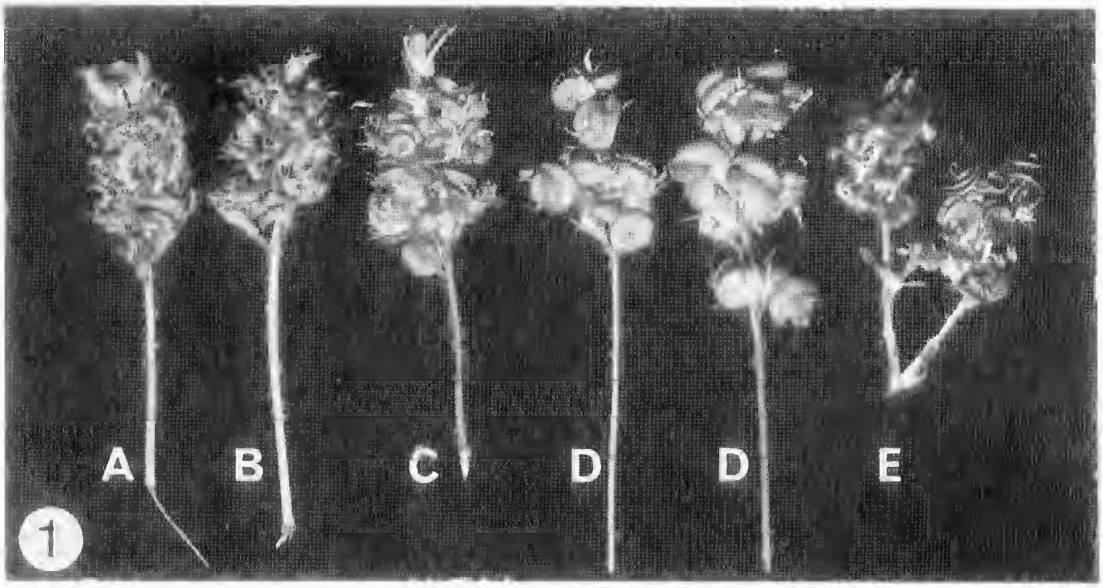

Fig. 1. Stages of pod development on lucerne plants: A, pods just forming; B, juvenile pods; C, young pods; D, mature green pods; E, mature brown (dry) pods.

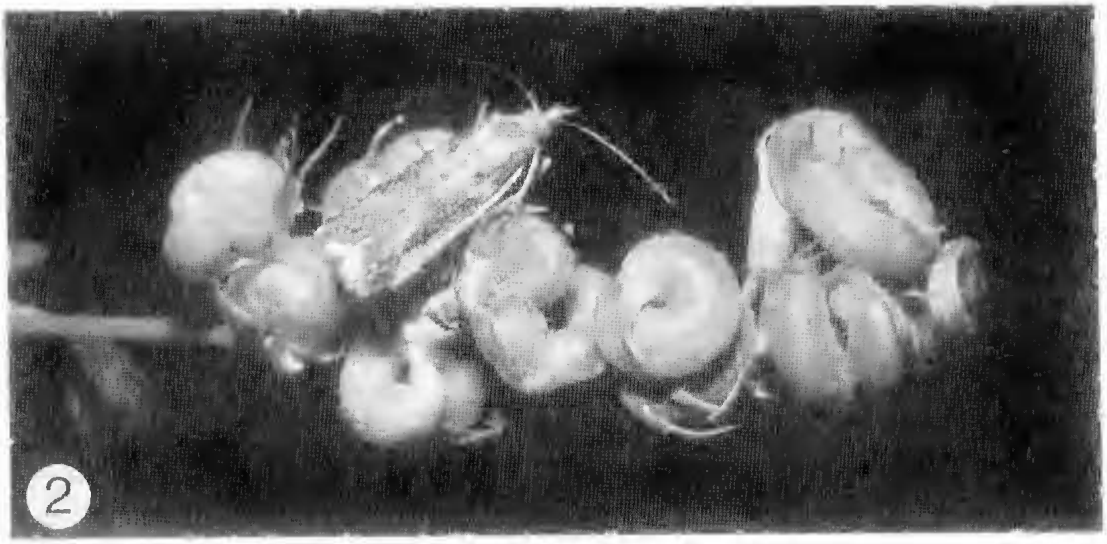

Fig. 2. Female *Etiella behrii* ovipositing onto a raceme of mature green lucerne pods.

forming, on juvenile pods or on mature brown pods. Therefore, in later samples racemes bearing only these stages were excluded from samples, and only racemes bearing some young and mature green pods were examined.

Later in the crop season, when the dryland crop had nearly all brown pods, similar samples were taken from an adjacent crop of irrigated lucerne, of the aphid resistant cultivar WL318, but counts were made of larvae only. Because of possible differences in numbers of larvae in young and in mature green pods, the numbers were expressed as stratified means per 1000 pods.

Rearing techniques and laboratory culture

Techniques for rearing field-collected *E. behrii* larvae through to the adult stage were developed so that a constant supply of each stage was at hand for life-history studies. Small larvae (1st and 2nd instars) collected from lucerne pods were successfully reared on a medium based on either powdered peas or lucerne seed (cf. Shorey & Hale 1965), but the agar had to be boiled for twice the suggested time for the medium to set. Each larva was placed in a 2.5 cm^3 vial containing 1.5 cm^3 of medium. Vials were sealed with hard plastic lids. The pupae were removed from the vials and placed in a dry container until the adults emerged. Both reared and field-collected adults were kept in gauze cages and given access to 10% sucrose solution. All stages were maintained in a dimly lit room held at 24-28°C and 75% R.H. in which the generation time was 25-35 days.

Cooper (1979)[1] obtained large numbers of *E. behrii* eggs from females ovipositing into the crevices of a darkened wooden box. We had no success with this method, nor with a variety of other surfaces including perspex, cardboard, freshly crushed lucerne, and rearing medium with lucerne seeds embedded in it. However, we obtained eggs laid onto freshly shelled peas or fresh mature green lucerne pods. Peas proved most successful because eggs could be easily and safely removed from their smooth surface. Eggs were more difficult to remove from lucerne pods because of their more complex surface. They were collected with a fine paint brush and transferred to a dry glass vial, and the 1st instar larvae were then transferred to a second vial containing rearing medium. With this method we initially obtained 80 eggs and reared 90% through to the adult stage.

Surveys of natural vegetation

Extensive surveys for *E. behrii* larvae were carried out in the native vegetation surrounding the irrigated lucerne growing area south of Keith (for approximately 8 km in each direction) and along road-sides between Tintinara and Willalooka (35 km north-west of Keith) in October-November, 1981. Extensive surveys were also conducted by one of us (DGT) in 1959-60 around Keith and Tintinara, and this information was extracted from the unpublished records of the (then) Department of Entomology, Waite Agricultural Research Institute.

[1]Cooper, D.J. (1979) "The Pathogens of *Heliothis punctigera* Wallengren". Ph.D. thesis, University of Adelaide, Unpubl.

Parasitoids and pathogens of E. behrii

To trap adults of known parasitoids of *E. behrii*, ten yellow pan traps filled with soapy water were placed around the edges of the irrigated WL318 lucerne crop and were examined once per week. The traps were run from early December 1981 to mid-February 1982. In addition, 41 late-stage *E. behrii* larvae (4th and 5th instars) collected from both the dryland and irrigated lucerne crops were reared on artificial diet in the laboratory to check for possible parasitoids. Similarly, one of us (DGT) collected large numbers of *E. behrii* larvae from both native and crop plants in 1959-60 to obtain parasitoids. Also, other workers have bred parasitoids from *E. behrii* collected in the Keith area over the last 40 years. Voucher material of parasitoids collected in the above manner has been lodged in the insect collection at the Waite Institute, and has been used to collate the data presented here.

Pathogens of 16 field-collected 4th and 5th instar larvae that died soon after in the laboratory were screened for pathogens by D.J. Cooper at Waite Institute using the methods of Cooper (1979)[1].

Results and Observations

Life history stages

At all stages of its life cycle *E. behrii* parallels descriptions of both the behaviour and the appearance of *E. zinckenella*, apart from being slightly smaller in size (Abul-Nasr & Awadalla 1957; Stone 1965; Singh & Dhooria 1971). The eggs are ovoid, averaging 0.6 mm in length (S.D. = 0.03; n = 50) and 0.4 mm in width (S.D. = 0.3), colourless when first laid, but soon turn pale yellow or orange. A day before hatching the black head capsules and prothoracic shields of the larvae are clearly visible through the chorion. Eggs are laid on either young or mature green pods, and are usually placed between the pod and the calyx or between the coils of the pod.

The frequency distribution of head capsule widths of field-collected larvae suggested five peaks and hence five instars (Fig. 3), but there was much variation between peaks. The range of each instar was better differentiated by the minima of a three-point moving average process (Fig. 3). The mean widths for five instars were then calculated as 0.18, 0.28, 0.44, 0.70, and 0.99 mm with multipliers between means, for Dyar's law, of 1.54, 1.59, 1.60 and 1.41. Five instars were also confirmed from the rearing of *E. behrii* in the laboratory. The 1st instar has a pale yellow body and a very distinctive black head capsule and prothoracic shield. Soon after hatching it constructs a fine funnel-like silk tube around itself with one end attached to the surface of the pod, it then chews through the pod and into a seed where it remains feeding. The entrance hole in the pod quickly heals over, the web tube soon disintegrates, and no evidence remains to indicate that the pod is infested. The larva does not normally leave this first seed until most of its contents are devoured. It then attacks the next seed in the pod, although it is now too large to get inside it. By the late 3rd to early 4th instar, the larva chews its way out of the original pod and enters one or more new pods, eating some (and occasionally all) of the seeds within. Commonly, at this stage most seeds are only partly devoured. The larva now has a black head capsule, semi-circular prothoracic shield and spiracles. The pro- and mesothorax are golden-brown, the metathorax and abdomen pale green. There are seven dorsal and lateral longitudinal pale golden-brown stripes on the body. By the late 4th instar the larva attacks several pods, meshing these and its frass together with silk to form a protective tent. This webbing is the first readily observed outward sign that *E. behrii* has attacked a crop. By the 5th instar the larva has a pale golden-brown head with dark brown mandibles. The prothoracic shield is still black but the rest of the body is green with a pinkish tinge to the abdomen. The longitudinal bands are more diffuse and pinkish. This final instar becomes a steadily darker pink, the green being masked completely just prior to pupation. Pupation takes place a few centimetres beneath the surface of the soil, inside a cocoon of silk, which incorporates particles of soil.

Adult moths are small (10-15 mm long), greyish and distinctive because of their typical 'snout' (formed by the forward-directed palps), the white stripe along the full length of the leading edge of each fore wing, and the transverse orange band near the base of each fore wing (Fig. 2). At rest, moths have an 'alert' appearance with the head and thorax raised and the abdomen and distal ends of the wings touching the surface. The antennae of the female are smooth and undifferentiated while those of the male have an enlarged basal segment and a 'bush' of scales on the elongated second segment. The maxillary palps of the female diverge at their second joint to form an open 'V' at the tip of the snout. These palps are parallel in the male moth.

Host plants and sources of infestation

Table 1 lists all the plant species for which *E. behrii* larvae have been recorded feeding on their seed in S.A. from 1959 to 1982. Larvae have also been recorded on many of the listed exotic species in other states, as well as on soybean *(Glycine max* (L.) Merrill), peanuts *(Arachis hypogaea* L.) and *Acacia cyclops* A. Cunn. ex G. Don in Western Australia, Northern Territory (Common 1990) and Queensland (Turner 1980). Of all these hosts, lucerne is the most commonly and severely attacked, but the species also causes sporadic damage to lupins, field peas and some clovers (Austin *et al.* 1986; DAM & DGT, unpubl.).

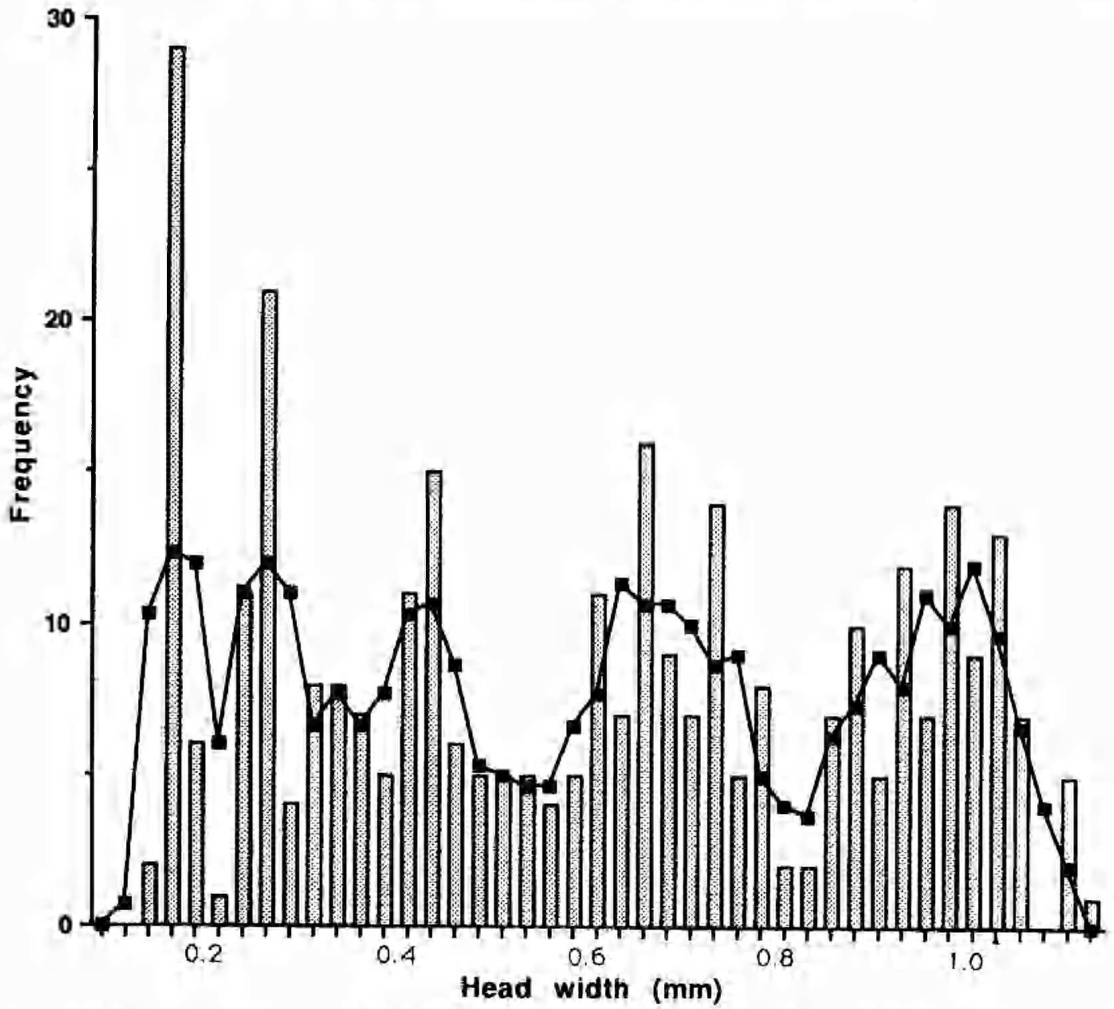

Fig. 3. Head capsule widths of larvae of *Etiella behrii* collected randomly from the field at 'Brecon' (Keith) (n= 329), expressed as a frequency distribution (histogram) and three-point moving averages (■).

The survey of native vegetation in late 1981 revealed that there is very little native scrub left in the Keith area, and what patches do remain are small, considerably disturbed and have very few native legumes, both in numbers of species and individual plants. Far more commonly encountered are volunteer plants of various exotic weed, crop and pasture legumes (especially lucerne) along road-sides, in clearings in scrubland, and in fields carrying other crops such as lupins. Lupins are a potential source of recent significance which have been planted more frequently in the Keith area since 1980. Lupins are planted from early winter to early spring, the seed ripening and drying out up until late November, thus providing an ideal early source of food for larvae, the adults of which emerge early in spring. Samples of 200 pods of green mature lupin pods taken from crops south of Keith and near Tintinara in early November, 1981 showed a small (<1%) infestation of *E. behrii* larvae.

Seasonal phenology

Observations in the laboratory indicate that females can lay more than 200 eggs and that eggs hatch within 24 h at 30-35 °C, but usually hatch after 4-7 days in the field in spring-summer. Larval duration in the field during spring-summer varied from 10-28 days and the pupal period from 14-21 days. Adults survived 7-21 weeks in the laboratory when held at ambient temperature and supplied with 10% sucrose solution.

The light-trap catches of adults at the Waite Institute campus in 14 day intervals for the period 1.iii.1959 to 18.ii.1960 are given in Fig. 4. These catches suggest

TABLE 1. *Known host plants of* Etiella behrii *in South Australia (records collected 1959-82).*

Native Legumes

Acacia victoriae Benth (elegant wattle)
Daviesia brevifolia Lindley (leafless bitter-pea)
Eutaxia microphylla (R. Br.) Black (Eutaxia, mallee bush-pea)
Hardenbergia violacea (Schnee.) Stearn (native lilac)
Pultenaea tenuifolia R. Br. ex Sims
Pultenaea densifolia F. Muell. (dense-leaved bush-pea)

Introduced Legumes

Cytisus scoparius (L.) Link (English broom)
Cytisus proliferus L.f. (tree lucerne)
Genista monspessulana (L.) L. Johnson (Montpellier broom)
Lupinus cosentinii Guss. (Western Australian blue lupin)
Lupinus angustifolius L. (lupin)
Lupinus uliginosus Schkyhr (birdfoot trefoil, greater lotus)
Medicago ciliaris (L.) Krocker
Medicago littoralis Rohde ex. Lois (strand medic)
Medicago polymorpha L. var. *polymorpha* (burr medic)
Medicago rugosa Desr. (gamma medic)
Medicago sativa L. (lucerne, alfalfa)
Medicago truncatula Gaertner (barrel medic, snail medic, caltrop medic)
Pisum sativum L. (field peas)
Trifolium fragiferum L. (strawberry clover)
Trifolium resupinatum L. (shaftal clover)
Trifolium subterraneum L. (subterranean clover)
Vicia dasycarpa Ten. (woolly-pod vetch)
Vicia villosa Roth. (hairy vetch, winter vetch)

at least four overlapping generations each year, with peak catches in late September (spring), late November and late December. There is then a generation with a peak in mid to late February and a hint of other small generations in March-May. Our trap catches for adults in December 1981 to January 1982 for the Keith area are in accordance with these earlier data by clearly detecting two large summer peaks (Fig. 6), even though they occurred at a slightly later time than the 1959-60 peaks. When related to monthly mean temperatures (Anon. 1987) by iterative calculations, these observations suggest a mean generation time of about 210 day degrees above about 13 °C.

South Australia has a hot dry summer (Anon. 1987) and as summer progresses, dryland lucerne should gradually becomes unfavourable for *E. behrii*. Our survey in dryland lucerne in the early summer of 1981-82 was planned to quantify this change; and in

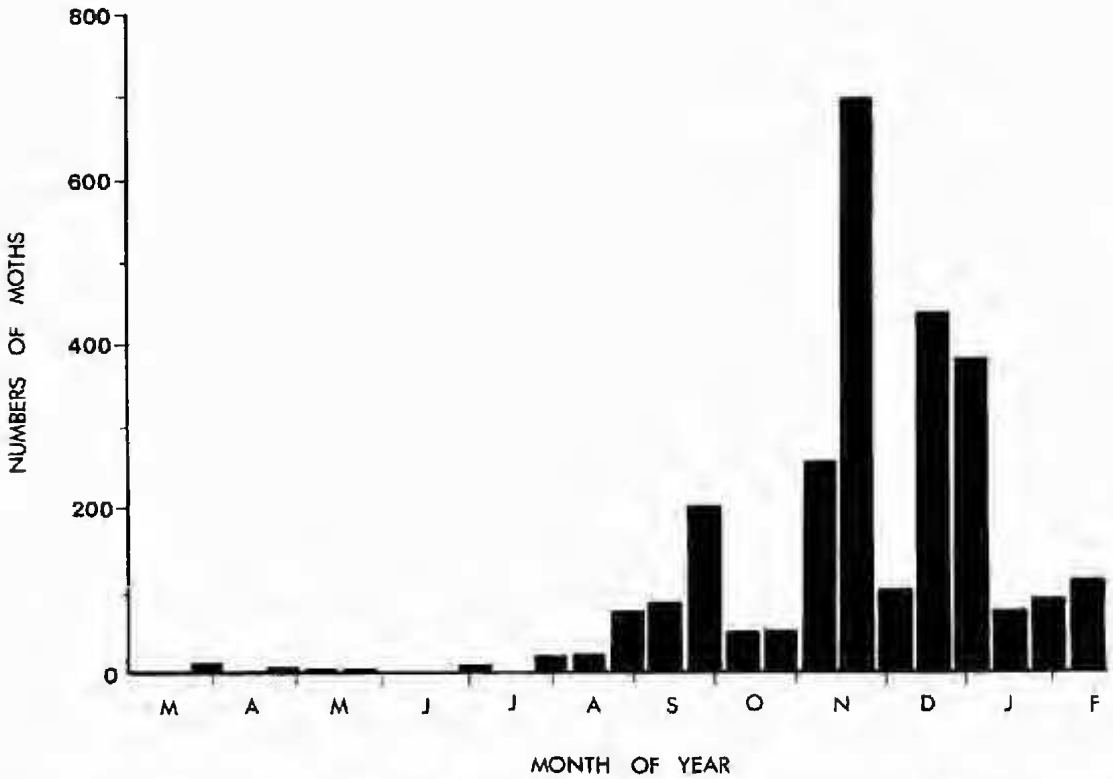

Fig. 4. Light-trap catches of adult *Etiella behrii* at the Waite Institute campus, Adelaide in 1959-60 accumulated in intervals of 14 days.

Table 2 are given, for each sample (a) the numbers of juvenile, young and mature green pods , and (b) the total number of eggs and larvae of *E. behrii* in young and mature green pods (none were found in juvenile pods).

The total numbers of *E. behrii* were obviously greater in mature green pods than in young ones from 6.i.82 onwards (Table 2), but the numbers of different stages were too small to allow comparisons between the two sorts of pods, except for eggs and 1st+2nd instars on 30.xii.81 and 6.i.82. For eggs on 30.xii.81 plus 6.i.82, there was a significantly greater number on young pods (51 on 1250 pods) than on mature green pods (31 on 1211 pods) ($\chi^2 = 3.95$, $p < 0.05$). For eggs plus 1st and 2nd instars, 78 on 1250 young pods were also significantly more frequent than 47 on 1211 mature green pods ($\chi^2 = 7.69$; $p < 0.01$). The comparison of these two sets of data suggest that in the samples for these two days some young larvae were failing to establish in the mature green pods. Obviously the larger number of all stages of *E. behrii* on mature green pods after 6.i.82 was therefore due to larger numbers of older larvae. Because the two types of pods could be considered as different sampling strata, the total numbers of *E. behrii* in each sample were subsequently expressed as means per 1000 pods, corrected for the different numbers of young and mature pods. Such means of all stages of *E. behrii* are also given in Table 2, and separate means for eggs and for instars 1+2, 3+4 and 5 are given in Fig. 5.

In Table 2, the decline with time of the numbers of both juvenile and young pods illustrates the maturation of the crop, and the data in Table 2 and Fig. 5 indicate a concomitant decrease in numbers of eggs and 1st + 2nd instars of *E. behrii* and an increase in numbers of older larvae. To try to make more sense of these trends, the numbers of eggs and of all larvae were plotted against the numbers of adults of *E. behrii* caught per week at the light trap at Keith (Fig. 6). The data suggest that the numbers of eggs laid up to and after the first peak of moths were strongly correlated with the numbers of moths each week. However, the

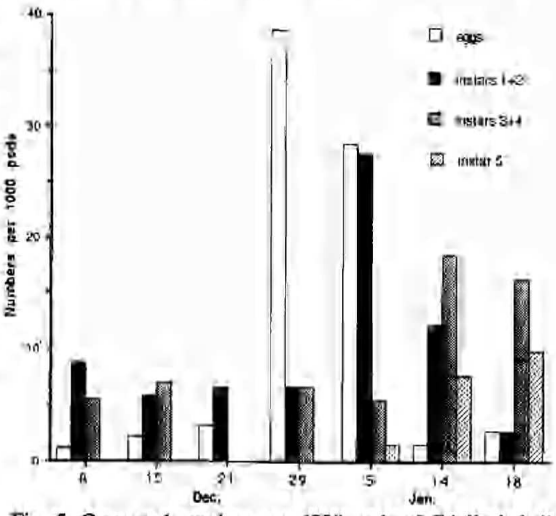

Fig. 5. Corrected numbers per 1000 pods of *Etiella behrii* eggs, 1st + 2nd instar, 3rd + 4th instar, and 5th instar larvae in a dryland lucerne crop at 'Brecon' (Keith) in relation to calendar time from 1.xii.1981.

numbers of eggs on 15.i.82 and 19.i.82 were much lower than expected in relation to the number of moths, which had increased to a second peak (Fig. 6). Unfortunately, no counts of eggs were made after 19.i.82 because attention was then diverted to the main irrigated seed crop which was in full flower.

The cause of the decline in numbers of eggs in the dryland crop on 15.i.82 and 19.i.82 (Figs 5, 6) is not known. There seemed to be an abundance of suitable pods for oviposition on these two dates (Table 2), but it is possible that the crop had dried out further so that even the young pods were subtly different from those on earlier dates and were unsuitable for oviposition. So too there was an unexpected decrease in the numbers of young larvae on 19.i.82 (Fig. 5), possibly again because the pods were not as suitable for their establishment as they had been earlier.

The numbers of larvae in irrigated lucerne seed crops were of particular interest to us from the view point

TABLE 2. *The numbers of juvenile (J) , young (Y) and mature green (M) pods in each sample; and the numbers of all stages of* E. behrii (E.b.) *in each category of pods.*

Date of sample	Numbers of pods			Numbers of *E.b.* in		Mean *E.b.* per
	J	Y	M	Y pods	M pods	1000 Y+M pods
09.12.81	276	804	91	10	4	15.6
16.12.81	362	637	207	7	6	15.4
22.12.81	267	573	330	6	3	10.0
30.12.81	113	650	542	30	33	52.9
06.01.82	95	600	669	21	57	61.5
15.01.82	17	187	463	2	24	40.0
19.01.82	15	238	1165	1	44	32.1
Total	1145	3689	3467	77	171	

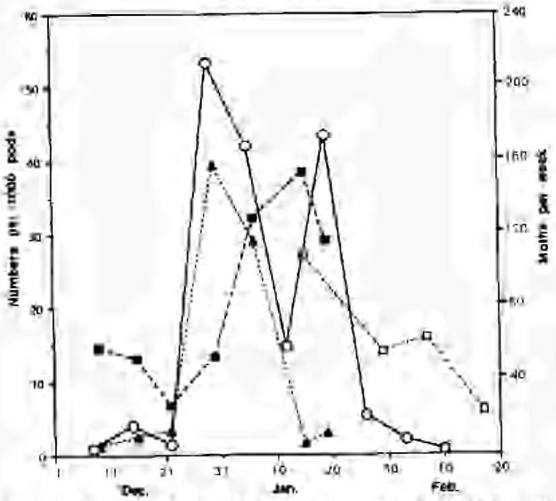

Fig. 6. Number of eggs (▲) and larvae (■) of *Etiella behrii* per 1000 pods in samples taken at 'Brecon' (Keith) in a dryland lucerne crop in the summer of 1981-82; the number of larvae (□) similarly sampled in an adjacent irrigated lucerne crop; and the number of moths (○) caught weekly in a light-trap in the same irrigated crop, in relation to calendar time from 1.xii.1981.

of pest management, and the irrigated and unsprayed WL318 crop, which we sampled later in the season, had been managed so that it flowered later than the adjacent dryland crop; and on 19.i.82 it was at about the same stage of development as the dryland crop had been on 9.xii.82. The numbers of larvae in the irrigated crop are also given in Fig. 6. On 15.i.82, they were about the same as those in the dryland crop on 15.i.82 and 19.i.82, but they similarly declined thereafter (Fig. 6) despite an abundance of seemingly suitable young and mature green pods for *E. behrii*. In particular, there was no increase in the numbers of larvae after the second peak of trapped moths on 19.i.82. Unfortunately, eggs were not recorded in these samples from the irrigated lucerne, nor were the larvae categorised into instars. It is not known, therefore, where the mortality occurred that caused the decreasing trend in larval numbers. The weather was not obviously unfavourable for moth survival and oviposition, so the mortality is likely to have been at the egg and/or larval stage. Two main possibilities may be suggested for this decline. Firstly, it is possible that there was a very low establishment of young larvae on the aphid resistant cultivar WL318, as Perrin (1978), for example, found in some varieties of cowpea attacked by *Cydia ptychora* (Meyrick). The second possibility is that the mortality was due to predators and pathogens. In particular, the decrease in larval numbers occurred at the same time as a dramatic increase in the numbers of *Campylomma livida* Reuter (dimpling bug), which is thought to be partly predacious, as is *C. verbasci* (Meyer), a well-known predator of mites, aphids and psyllids in Canada (McMullen & Jong 1970).

Finally, the second peak of moths in mid-January (Fig. 6) may be expected to be smaller than the first one because the area of dryland lucerne is much greater than that of irrigated lucerne and, as summer progresses, dryland lucerne is no longer favourable for *E. behrii*. So one might therefore expect fewer moths to be caught in a light-trap in February-March, as is partly illustrated in Fig. 6 for Keith. Other crops attacked by *E. behrii*, such as lupins, would similarly cease to produce suitable green pods for young caterpillars in mid January unless they were irrigated. Therefore, in most localities there would be a reduction in numbers of larvae in late January to early February and a subsequent reduction in the numbers of moths at the next peak catch of moths, as shown in Fig. 4 for Adelaide in mid to late February. The few moths flying in late February would find even fewer suitable pods for oviposition at the end of the hot dry summer. So the species is likely to be relatively rare in most localities after February and until the next flush of plant growth in spring, following winter rains. During this interval the species could either enter an obligate diapause or it could continue to breed in reduced numbers (on volunteer lucerne). The light-trap data for Adelaide (Fig. 4) strongly support the latter alternative, because a few moths were caught in late April to early May. The lack of a diapause was also demonstrated directly by one of us (DGT) by successfully incubating to adult emergence, larvae collected over the winter of 1959.

Parasitoids, predators and pathogens

The parasitoid species which have been recorded from *E. behrii* are given in Table 3 along with the stage from which they emerge, whether they are solitary or gregarious, and their status as either primary or hyperparasitoids. The ichneumonid *Temelucha cycnea* Kerrich and the braconid *Iconella alfalfae* (Nixon) have been recorded as causing between 2% and 11% mortality to field populations in the Keith area in 1959-60 (DGT unpubl.), while the other species listed have been only rarely encountered. Yellow pan-traps placed in the field at 'Brecon' in early December 1982 first caught *T. cycnea* in early February. The numbers of this parasitoid appeared to increase through February and March, but there were too few collected per trap to quantify differences between samples. *Phanerotoma* sp. was also caught in late February but in very low numbers.

Of 41 larvae of *E. behrii* taken from the field in late January to screen for parasitoids, 25 pupated, and three were parasitised (two by *T. cycnea* and one by *Panerotoma* sp.). *T. cycnea* oviposits into early stage larvae after the latter emerge from the pod and begin

to build a webbed retreat, while *Panerotoma* sp. oviposits into the eggs of its host. Both species then complete their development after the final host instar has dropped to the soil and pupated. During the 1981-82 study we did not record any other parasitoid species, even though *I. alfalfae* has been recovered in moderate numbers in the past (DGT unpubl.).

We did not directly observe any predation upon eggs and larvae of *E. behrii*, but several general predators were seen in lucerne crops, and they may feed on *E. behrii*. The predators included *C. livida* (see above) and spiders, particularly of the families Oxyopidae, Araneidae, Lycosidae and Thomisidae. Of these species *C. livida* was by far the most common in irrigated crops during January-February 1982.

Sixteen of the 41 screened larvae died before they pupated. After death they became soft, darker in colour and developed faint spots under the integument. These larvae were later examined and found to contain large numbers of microsporidian spores and some bacteria (*Bacillus* sp. — possibly *B. thuringiensis* Berlinger) in the haemolymph. Nothing is known of the mortality caused by these pathogens in the field, but *B. thuringiensis* at least is known to be highly toxic to *E. behrii* larvae in the laboratory, having an LC_{50} value of 311 spores/mm^3, a figure 20 times lower than that for *Helicoverpa armigera* (Hübner) (Cooper 1983).

Discussion

Irrigated lucerne crops flower and form pods later than dryland lucerne and volunteer plants which grow around irrigated crops, along road-sides and in scrubland. So the number of moths available to attack irrigated lucerne crops each year should depend on the number and suitability of pods available to the earlier generations of *E. behrii* in that season, and on some function of weather. However, the very low numbers of larvae in the irrigated crop south of Keith in January-February 1982, despite the presence of a large number of adult moths in the vicinity (Fig. 6) and suitable oviposition sites, suggests that some variable or variables, other than the number of moths, may be a key factor in the amount of crop damage that occurs from year to year. This variable might be predation or parasitism on eggs and young larvae, the effect of pathogens, or some property of the plant which prevents young larvae establishing and surviving in pods, either of certain cultivars or in certain years. Such a variable might also account for the unpredictability of attack of lucerne by *E. behrii*. In most years damage is so slight as to go unnoticed, but occasionally there is a very heavy infestation in one season. Such outbreak seasons appear from the available records to be infrequent, but when they do occur, outbreaks are widespread. To date, further research aimed at examining the factors responsible for heavy infestations of *E. behrii* in seed lucerne crops in South Australia, has been hindered by the infrequency of such events. In recent years there have been only low or moderate numbers of this pyralid pest reported in seed crops in the Keith area, possibly because of the more widespread and effective use of pesticides since the early 1980's.

TABLE 3. *Parasitoids known to attack various stages of* Etiella behrii *in South Australia (records collected 1959-82).*

Parasitoid species	Stage from which parasitoid emerges	Primary (P) or hyperparasitoid (H) solitary (S) or gregarious (G)
Ichneumonidae		
Temelucha cycnea Kerrich	pupa	P;S
Enytus sp.	?	P;S
Braconidae		
Iconella alfalfae (Nixon)	5th instar larva	P;S
Phanerotoma sp.	pupa	P;S
Bassus sp. 1	5th instar larva	P;S
Bassus sp. 2	5th instar larva	P;S
Bracon sp.	mature larva	P;S
Elasmidae		
Elasmus sp.	pupa	H;S or G
Eurytomidae		
Eurytoma sp.	pupa	P;S
Tachinidae		
? Siphonini (gen. & sp. indet.)	mature larva	P;S

Acknowledgments

We wish to thank Mr A. Campbell for access to his property, 'Brecon', Dr David Cooper for assaying pathogens of *Etiella*, Dr Jenny Gardner for identification of native plants, and Drs Brian Cantrell and Mike Sharkey for identification of dipteran and hymenopteran parasitoids, respectively. We gratefully acknowledge the Commonwealth Special Research Grants Scheme and the lucerne seed growers through the Seed Section of the United Farmers and Stock Owners of South Australia Inc. for funding this project. We also thank Paul Dangerfield for providing technical assistance in the preparation of the manuscript.

References

ABUL-NASR, S. & AWADALLA, A.M. (1957) External morphology and biology of the bean pod-borer, *Etiella zinckenella* Treit. (Lepidoptera: Pyralidae). *Bull. Soc. ent. Egypte* **41**, 591-620.

ANON. (1987) Biennial Report of the Waite Agricultural Research Institute, The University of Adelaide, 1986-1987 (University of Adelaide, Adelaide).

AUSTIN, A.D., DURHAM, M. & BAILEY, P. (1986) Etiella Moth. Department of Agriculture, South Australia, Fact Sheet, FS 51/85, 4pp.

COMMON, I.F.B. (1990) "Moths of Australia." (Melbourne University Press, Melbourne).

COOPER, D.J. (1983) The susceptibility of *Etiella behrii to Bacillus thuringiensis*. *J. Aust. ent. Soc.* **22**, 93-95.

DURHAM, M.S. (1984) Commercial monitoring of insect pests and beneficials of seed lucerne in south east South Australia. pp. 121-127 *In* Bailey, P. & Swincer D. (Eds) "Proceedings of the 4th Australian Applied Entomological Research Conference." (South Australian Government Printer, Adelaide).

HARDSTACK, A.W., HENDRICKS, D.E., LOPEZ, J.D., STADELBACHER, E.A., PHILLIPS, J.R. & WITZ, J.A. (1979) Adult sampling. pp. 105-131. *In* Sterling, W.L. (Ed.) "Economic Threshholds and Sampling of *Heliothis* Species on Cotton, Corn, Soybean and Other Plants." Southern Cooperative Services Bulletin No. 231. (Texas A & M University, College Station).

MAELZER, D.A., PINNOCK, D.E., BAILEY, P.T. & MADGE, P.E. (1982a) Pollination and pest management of lucerne seed crops in South Australia. pp. 121-141. *In* Cameron, P.J., Wearing, C.H., & Kain, W.M. (Eds) "Proceedings of the Australian Workshop on Development and Implementation of I.P.M." (Government Printer, Auckland).

———, ——— MADGE, P.E. & BAILEY, P.T. (1982b) Pollination and arthropod pest management of lucerne seed crops in South Australia. pp. 385-392. *In* Lee, K.E. (Ed.) "Proceedings of the 3rd Australasian Conference on Grassland Invertebrate Ecology." (South Australian Government Printer, Adelaide).

MCMULLEN, R.D. & JONG, C (1970) The biology and influence of pesticides on *Campylomma verbasci* (Heteroptera: Miridae). *Can. Ent.* **102**, 1390-1394.

PERRIN, R.M. (1978) Varietal differences in the susceptibility of cowpea to larvae of the seed moth, *Cydia ptychora* (Meyrick) (Lepidoptera: Tortricidae). *Bull. ent. Res.* **68**, 47-56.

SHOREY, H.H. & HALE, D.L. (1965) Mass rearing of the larvae of nine noctuid spp. on a simple artificial medium. *J. econ. Ent.* **58**, 522-524.

SINGH, H. & DHOORIA, M.S. (1971) Bionomics of the pea pod borer, *Etiella zinckenella* (Treitschke). *Ind. J. Ent.* **33**, 123-130.

STONE, M. (1965) Biology and control of lima bean pod-borer in southern California. *Tech. Bull. U.S.D.A.* **1321**, 1-46.

TURNER, J.W. (1980) Insect pests of peanuts in eastern Queensland. *Qld Agric. J.* **106**, 172-176.

WHALLEY, P.E.S. (1973) The genus *Etiella* Zeller (Lepidoptera: Pyralidae): a zoogeographic and taxonomic study. *Bull. Br. Mus. (Nat. Hist.) Ent.* **28**, 1-21.